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## Species Composition, Abundance and Distribution of Phytoplankton in the Thermocline Layer in the South China Sea, Area IV: Vietnamese Waters

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### ABSTRACT

One hundred and eighty-five samples of phytoplankton were collected from 58 stations in the Vietnamese waters during 30 April – 29 May 1999 to investigate species composition, abundance and distribution in the thermocline layer compared with those in the surface layer. The samples were taken from surface, thermocline depth and chlorophyll maximum depth. In this study, thermocline depth and chlorophyll maximum depth were included in the thermocline layer. Three hundred and fifty-seven taxa, composed of 2 species of blue green alga, 159 species of diatoms and 161 species of dinoflagellates, were identified. The occurrence of species in each layer were recorded. The cell densities at chlorophyll maximum depth were highest among the sampling depths observed in most stations of the survey. Data obtained from the samples collected from surface to 150 m with 25 m interval to study vertical distribution indicates that maximum cell density of the water column presented between 60–110 m. The most abundance was 179,386 cells/l found at chlorophyll maximum depth near the Ca Mau Cape due to the bloom of many diatom species. *Oscillatoria* ( *Trichodesmium* ) *erythraea*, *Proboscia alata*, *Pseudosolenia calcar-avis* and *Thalassionema frauenfeldii* were dominant at all sampling depths. Five species of diatoms presented as dominant species only in the thermocline layer. *Alexandrium* was frequently found at surface through chlorophyll maximum depth in the south. Diversity and evenness indices of all sampling depths were high in the Gulf of Tonkin and decreased through the south of Vietnam. These indices were high in the thermocline layer.

**Key words :** Phytoplankton, thermocline layer, South China Sea, Vietnamese waters

### Introduction

A study on distribution, abundance and species composition of phytoplankton in the South China Sea has been carried out since 1995 as one title of the Interdepartmental collaborative Program. The investigations were done in the Area I ( Gulf of Thailand and east coast of Peninsular Malaysia), Area II (Sabah, Sarawak and Brunei Darussalam) and Area III (western Pilippines). The last area was focused on phytoplankton in the thermocline layer [Boonyapiwat (1999a, 1999b, 2000)].

The earliest study on plankton in Vietnamese waters was reported by Rose (1926). From that time, many surveys have been carried out in both coastal and offshore area [Koi *et al.* (1995)]. After 1963, about 1,700 species of freshwater and marine plankton were arranged for the first time in Vietnam by hand of A. Shirota [Shirota (1966, 1967)]. However, phytoplankton in the thermocline layer and subsurface chlorophyll maxima in this region are unknown.

Subsurface chlorophyll maxima or deep chlorophyll maxima are well known phenomenon in temperate, subtropical and tropical oceanic regions. They are usually found at the depths around or below the seasonal thermocline [Saijo *et al.* (1969), Furuya and Marumo (1983)]. Thermocline zone

is the productive area that thermocline ridges have been found to be the place where tunas aggregate [Silas and Pillai (1982)]. The most abundance of phytoplankton in the water column and high diversity were observed in this layer [Boonyapiwat (1999b, 2000)].

The purpose of this study is to describe species composition, abundance and distribution of phytoplankton in the thermocline layer compared with those in the surface layer and to determine species diversity indices.

## **Materials and Methods**

### *Sampling, counting and identification*

The survey was carried out on board M/V SEAFDEC during 21 April – 5 June 1999 in Vietnamese waters. Phytoplankton samples were collected from 58 stations during 30 April – 29 May 1999 [Fig.1]. The study area was divided into 3 parts as north (stations 1-10), central (stations 11 – 32) and south (stations 33 – 58). One hundred and eighty five samples were taken with Van Dorn water sampler from surface, the beginning of thermocline or thermocline depth and chlorophyll maximum depth. The sampling depths were determined using ICTD record at each station. The samples of 9 stations along 110° E were collected from surface to 150 m with 25 m interval for study on vertical distribution [Fig.1].

The water samples of 30 – 40 l were filtered through 20 mm mesh phytoplankton net and preserved with 1% formalin immediately. All samples were concentrated by sedimentation. Phytoplankton in the concentrated samples were counted and identified by using a small counting slide (0.25 ml), compound microscope fitted with a phase contrast device, inverted microscope and the electron microscope, both scanning electron microscope (SEM) and transmission electron microscope (TEM). Filament count was done for blue green algae.

### *Statistical analysis*

The species diversity indices [richness index (R), diversity index (H) and evenness index (E)] were computed according to the methods in Ludwig and Reynolds (1988). The equations are as follows:

$$R = \frac{s}{\sqrt{n}}$$

$$H' = - \sum_{i=1}^s [(n_i / n) \ln (n_i / n)]$$

$$E = \frac{(1/\lambda)-1}{e^{H'} - 1}$$

$$\lambda = \sum_{i=1}^s \frac{n_i(n_i-1)}{n(n-1)}$$

Where :  $s$  = the total number of species  
 $n$  = the total cell number  
 $n_i$  = the cell number of species  $i$

## Results

### *Thermocline and chlorophyll maximum depth from ICTD records*

The thermocline depths (the depths at the beginning of thermocline) varied from 29 – 45 m, 12 – 50 m and 20 – 60 m in the north, central and south of the study area respectively. The chlorophyll maximum depths were found below thermocline depths and existed in the thermocline layer or thermocline zone. They were in the range of 40 – 72 m, 28 – 110 m and 14 – 90 m in the north, central and south respectively [Table 1]. At shallow stations, thermocline depths were not detected and chlorophyll maximum depths mostly reached near the bottom.

### *Identification*

A total of 357 taxa, composed of 2 genera, 2 species of blue green alga, 62 genera, 159 species of diatoms and 37 genera, 161 species of dinoflagellates, were identified from the samples of this survey. The taxonomic list is given in Table 2.

### *Abundance and distribution*

Total phytoplankton cell densities of the surface layer were abundant in the coastal area [Fig.2]. The abundance were noticed at the northern part of the study area or the Gulf of Tonkin and the southern part where the highest cell count of 115,925 cells/l near Ca Mau Cape was found. The cell density decreased with distance from the coast. The distribution pattern of blue green algae, diatom and dinoflagellate in the surface layer are shown in Figs. 3 – 5. Blue green algae was abundant and distributed in large area of the Gulf of Tonkin especially in coastal area while densities at the offshore stations were higher than those at the coastal stations in the central part. Like total phytoplankton, distribution and abundance of diatom and dinoflagellate showed the same pattern. The highest cell count of these 2 groups were found at the west coast of Ca Mau Cape.

The cell densities of total phytoplankton at 3 sampling depths shown in Figs. 6 – 8 reveal that highest density of almost all stations were observed at chlorophyll maximum depth except stations 4, 7, 38 & 49 where surface densities were highest. The maximum cell count was 179,386 cells/l found at chlorophyll maximum depth near the Ca Mau Cape. The vertical cross section along 110° E from 8° N – 16° N indicates that the maximum cell density of the water column presented between 60 – 110 m [Fig. 9].

The ranges of phytoplankton density at different depths in 3 parts of study area are shown in Table 1. The densities of 3 groups of phytoplankton (blue green algae, diatom and dinoflagellate) were low at thermocline depth in the whole area. Blue green algae density was high at surface in the Gulf of Tonkin. Diatom densities were relatively high at surface and chlorophyll maximum depth of the southern part while dinoflagellate densities showed less variation. The species number of diatom and dinoflagellate were highest at chlorophyll maximum depth and thermocline depth respectively [Table 3].

### *Vertical distribution of species*

Most of phytoplankton species presented from surface through chlorophyll maximum depth [Table 2]. The species occurred predominant at all sampling levels were *Oscillatoria* (*Trichodesmium*) *erythraea*, *Proboscia alata*, *Pseudosolenia calcar – avis* and *Thalassionema frauenfeldii*. Thirty - four species of diatom were found below the mixed layer. Among these species, *Asteromphalus sarcophagus*, *Cocconeis* spp. and *Coscinodiscus reniformis* occurred only at chlorophyll maximum depth. *Chaetoceros radicans* were never observed at surface but frequently found at thermocline depth and occurred as dominant species at chlorophyll maximum depth. Dinoflagellate species were not abundant at any sampling level. Distribution of many species limited by depths. Thirteen species presented

only at surface while 55 species occurred in the thermocline layer (thermocline depth and chlorophyll maximum depth), and 11 species were found only at chlorophyll maximum depth such as *Alexandrium concavum*, *Ceratium platycorne*, *Prorocentrum concavum* and *P. emarginatum*.

#### *Dominant species*

There were 10, 5, and 13 species dominated phytoplankton population at surface, thermocline depth and chlorophyll maximum depth respectively. *Oscillatoria erythraea* distributed with highest relative abundance at surface in most of the study area. *Pseudosolenia calcar – avis* and *Thalassionema frauenfeldii* occurred predominant at surface in the central part while *T. nitzschoides* was abundant at the coastal area [Fig.10]. *Pseudosolenia calcar – avis* also distributed at thermocline depth in large area of the central part and reached to chlorophyll maximum depth at some stations. *Thalassionema frauenfeldii* was the dominant species at chlorophyll maximum depth distributed in most of the study area except the Gulf of Tonkin. [Figs.11 & 12].

#### *Occurrence of toxic dinoflagellate*

Low cell densities of toxic dinoflagellates were observed in this survey. *Alexandrium* was the selected genus for studying its distribution. It was frequently found at surface through chlorophyll maximum depth in the southern part of study area. The highest cell count, 25 cells/l, was observed at chlorophyll maximum depth at station 44 [Fig.13].

#### *Species diversity indices*

Based on the data obtained from the entire list of taxa at all sampling depths, richness indices, diversity indices and evenness indices were computed and summarized in Table 3. They varied considerably at surface in the Gulf of Tonkin due to the bloom of *Oscillatoria erythraea* at station 7 that led to low diversity and evenness index. In comparison with the Gulf and the central part, the values in the southern part was lowest. High richness indices were found in the central part. The average diversity and evenness indices of all sampling depths were high in the Gulf and decreased through the southern part of study area. These indices high in the thermocline layer.

## **Discussion and Conclusion**

The thermocline and chlorophyll maximum depth of the present study area except the Gulf of Tonkin were observed in the deeper level than those of the Area II, Sabah, Sarawak and Brunei Darussalam [Boonyapiwat (1999b)] and nearly the same level as those of the Area III, western Philippines [Boonyapiwat (2000)] in the same period of the year. The Gulf of Tonkin is shallower and thermocline layer occurred at some stations that differed from the aforementioned areas.

Previous study of phytoplankton in Vietnamese waters revealed that cell density was less than that of the present study. The review of studies on phytoplankton in the sea waters of Vietnam during 70 years, 1924 – 1994 reported by Koi *et al.* concluded that the peak of density reached to 6,700 cells/l during January – March in the Gulf of Tonkin and 342 species of phytoplankton with density of 248 cells/l in the south of Vietnam were observed in 1985. Thuoc (1997) found 192 species in Bach Long Vy waters and high density of 1,000 – 10,000 cells/l were determined in October. The present study shows the observation at chlorophyll maximum depth where phytoplankton was abundant and numerous species presented. Furuya and Marumo (1983) investigated phytoplankton community in the subsurface chlorophyll maxima in the western North Pacific Ocean and found that chlorophyll-a concentration of this layer was 2.1 – 7.5 times higher than that of the



surface and high cell counts were observed. Boonyapiwat (1999b, 2000) also reported high cell density in the thermocline layer. The high cell density at surface of some stations in this survey was probably due to the upwelling.

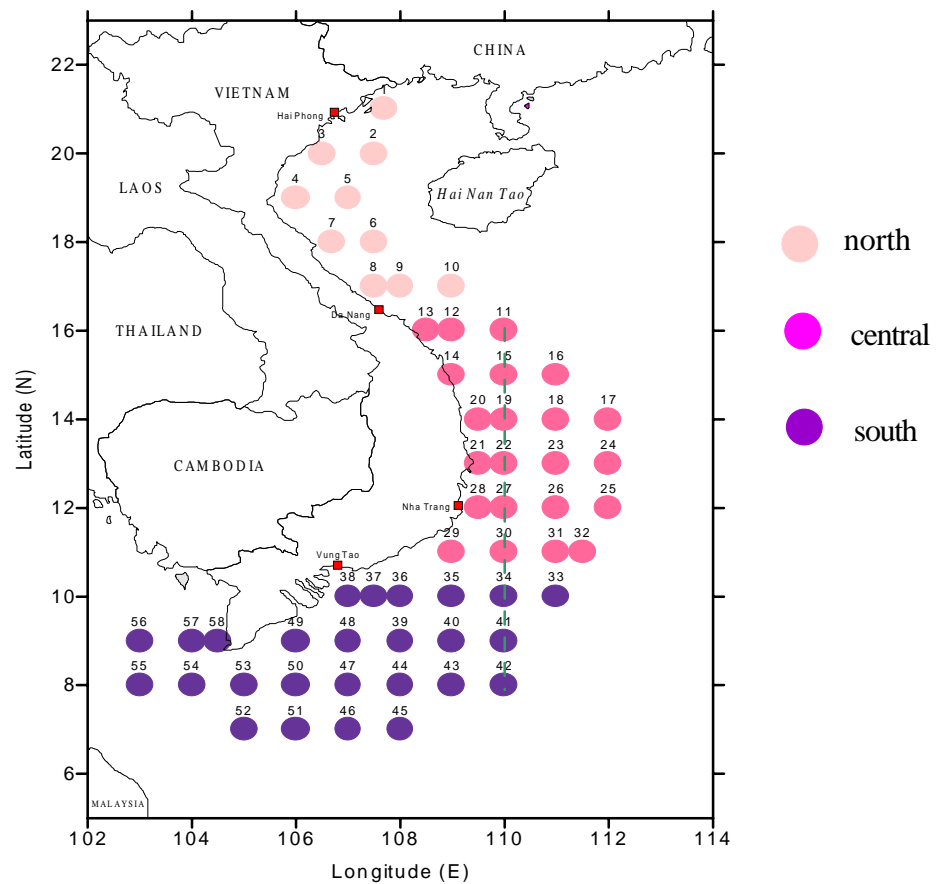
In the post- NE monsoon period, surface current flowed southerly from the north of Vietnam along the coast and from the east coast of the Gulf of Thailand to the Ca Mau Cape [Shirota (1966)]. The current from both directions transported nutrients from the coast especially Mekong Delta to the Cape and caused phytoplankton blooms. The Gulf of Tonkin was the productive area. The present study shows high cell density of most stations in the Gulf. Nutrient – enriched water from land were brought by river – runoff into the Gulf and influenced phytoplankton blooms. Thuoc (1996), studied phytoplankton in the Tien Yen, Bach Dang and Red rivermouths, concluded that cell density in the Red rivermouth was high.

Most of phytoplankton species occurred in the thermocline layer seemed to be similar to those observed in the Area II and Area III and more taxa were observed in the present study [Boonyapiwat (1999b, 2000)]. The succession of *Oscillatoria erythraea* in the southern part of Vietnam was recorded as the characteristic of this area [Shirota (1966)]. Some dominant species were different from those in the Area II and Area III such as *Guinardia flaccida* and *Hemiaulus membranacea*. *Thalassionema frauenfeldii* and *Chaetoceros lorenzianus* also dominated phytoplankton population in the chlorophyll maximum layer of the East China Sea [Saijo *et al.* (1969)].

Although small number of toxic dinoflagellates were observed, many species presented in this area. The highest cell count (25 cells/l) of *Alexandrium* in this survey was more than that in the Area I (17 cells/l) and Area III (4 cells/l) but less than that in the Area II (36 cells/l) [Boonyapiwat (1999a, 1999b, 2000)]. It indicates that *Alexandrium* distributed all over the South China Sea.

The diversity and evenness indices of phytoplankton in the thermocline layer of the area were high that was similar to the results of the Area II and Area III [Boonyapiwat (1999b, 2000)]. Furuya and Marumo (1983) reported high diversity (>4.0) and evenness indices (0.8) of the samples collected from the subsurface chlorophyll maximum layer in the western North Pacific Ocean. Owing to the blooms of *Oscillatoria erythraea* at surface and thermocline depth, the species diversity indices were low at some stations.

It is concluded that phytoplankton density in the Vietnamese waters during April – May 1999 was high at surface through chlorophyll maximum depth in the Gulf of Tonkin and near the Ca Mau Cape. Phytoplankton was rather low at surface and high in the thermocline layer in most stations of the survey. The occurrence of some phytoplankton species were limited by depths. Toxic dinoflagellates presented from surface through the thermocline layer in low cell densities. *Alexandrium* distributed throughout the South China Sea. The diversity and evenness indices were high in the thermocline layer. Low indices caused by the blooms of *Oscillatoria erythraea*.



**Fig. 1.** Location of sampling stations in 3 parts of study area. The dashed line indicates the transect where vertical cross section is made.

**Table 1.** Ranges of phytoplankton densities at sampling depths in 3 parts of study area.

SD = Sampling depth      BG = Blue green algae  
S=Surface      Th = Thermocline depth      Ch = Chlorophyll maximum depth

Part	Station	Depth (m)	SD (m)	Phytoplankton (cells/l)	BG (filaments/l)	Diatom (cells/l)	Dinoflagellate (cells/l)
North (Gulf of Tonkin)	1-10	26-110	S : 2-4 Th : 29-45 Ch : 20-72	503-62,506 632-1,167 567-39,811	35-11,427 90-165 0-1,495	304-57,821 403-615 302-40,820	67-2,011 140-150 46-2,219
Central	11-32	42-4,117	S : 2-4 Th : 12-50 Ch : 28-110	283-12,093 306-878 532-15, 820	0-780 0-205 0-684	105-9,749 71-563 395-15,300	71-1,188 61-249 35-1,456
South	33-58	20-3,385	S : 2-4 Th : 20-60 Ch : 14-90	324-115,925 351-1,238 578-179,386	71-2,600 16-1,080 0-9,100	87-113,290 59-548 463-176,415	48-2,229 21-118 14-2,414

**Table 2.** Taxonomic list and occurrence of phytoplankton at different sampling levels.

S = Surface, Th= Thermocline depth, Ch= Chlorophyll maximum depth

x = present, xx = frequent, xxx = abundant

Species	Sampling levels		
	S	Th	Ch
Phylum Cyanophyceae ( Blue green algae )			
<i>Calothrix crustacea</i> Schouseboe & Thuret	x	x	x
<i>Oscillatoria</i> ( <i>Trichodesmium</i> ) <i>erythraea</i> ( Ehrenberg ) Kutzing	xxx	xxx	xxx
Phylum Bacillariophyceae ( Diatom )			
<i>Achnanthes</i> spp.	-	x	x
<i>Actinocyclus</i> spp.	xx	xx	xx
<i>Actinoptychus senarius</i> ( Ehrenberg ) Ehrenberg	xx	x	x
<i>Asterolampra marylandica</i> Ehrenberg	xx	xx	xx
<i>Asteromphalus elegans</i> Greville	x	-	-
<i>A. heptactis</i> ( Bre'bisson ) Greville	xx	x	-
<i>A. flabellatus</i> ( Bre'bisson ) Greville	x	x	-
<i>A. sarcophagus</i> Wallich	-	-	x
<i>Azpeitia africana</i> ( Janisch ex A. Schmidt ) G. Fryxell & T.P. Watkins	-	x	x
<i>A. nodulifera</i> ( A. Schmidt ) G. Fryxell & P.A. Sims	xx	x	xxx
<i>Bacillaria paxillifera</i> ( O.F. Muller ) Hendey	x	xx	xx
<i>Bacteriastrium comosum</i> Pavillard	xx	xx	xx
<i>B. delicatulum</i> Cleve	xx	xx	xx
<i>B. elongatum</i> Cleve	x	xx	xx
<i>B. furcatum</i> Shadbolt	x	xx	xx
<i>B. hyalinum</i> Lauder	x	x	x
<i>B. minus</i> Karsten	-	x	x
<i>Bellerochea horologicalis</i> von Stosch	xx	x	-
<i>B. malleus</i> (Brightwell) van Heurck	x	x	-
<i>Bleakeleya notata</i> ( Grunow ) Round	-	x	-
<i>Campylodiscus</i> spp.	x	xx	xx
<i>Cerataulina bicornis</i> ( Ehrenberg ) Hasle	x	x	x
<i>C. pelagica</i> ( Cleve ) Hendey	x	x	x
<i>Chaetoceros aequatorialis</i> Cleve	x	x	-
<i>C. affinis</i> Lauder	xx	xx	xx
<i>C. affinis</i> var. <i>willei</i> (Gran) Hustedt	-	x	xx
<i>C. anastomosans</i> Grunow	x	x	-
<i>C. atlanticus</i> Cleve	x	xx	xx
<i>C. atlanticus</i> var. <i>neapolitana</i> (Schroder ) Hustedt	-	x	xx
<i>C. aurivillii</i> Cleve	x	xx	-
<i>C. bacteriastroides</i> Karsten	-	x	-
<i>C. brevis</i> Schütt	x	-	-
<i>C. buceros</i> Karsten	x	-	-
<i>C. castracanei</i> Karsten	-	x	-
<i>C. clavigera</i> Ostenfeld	x	x	-
<i>C. coarctatus</i> Lauder	xx	xx	xx
<i>C. compressus</i> Lauder	xxx	xx	xxx
<i>C. costatus</i> Pavillard	x	x	-
<i>C. curvisetus</i> Cleve	x	x	-
<i>C. dadayi</i> Pavillard	x	x	x
<i>C. danicus</i> Cleve	-	x	x
<i>C. debilis</i> Cleve	x	x	-
<i>C. decipiens</i> Cleve	x	x	x

**Table 2.** (Continued).

Specices	Sampling levels		
	S	Th	Ch
<i>C. densus</i> (Cleve) Cleve	X	X	-
<i>C. denticulatus</i> Lauder	XX	XX	XX
<i>C. didymus</i> Ehrenberg	XX	XX	X
<i>C. diversus</i> Cleve	XX	XX	XX
<i>C. laevis</i> Leuduger - Fortmorel	XX	XX	XX
<i>C. lorenzianus</i> Grunow	XXX	XX	XXX
<i>C. messanensis</i> Castracane	XX	XX	XXX
<i>Chaetoceros nipponicus</i> Ikari	X	X	X
<i>C. paradoxus</i> Cleve	XX	X	-
<i>C. peruvianus</i> Brigtwell	XXX	XX	XX
<i>C. pseudocurvisetus</i> Mangin	XXX	XX	XXX
<i>C. pseudodichaeta</i> Ikari	XX	XX	XX
<i>C. radicans</i> Shutt	-	XX	XXX
<i>C. rostratus</i> Lauder	X	X	X
<i>C. seiracanthus</i> Gran	X	XX	X
<i>C. siamensis</i> Ostenfeld	X	X	-
<i>C. simplex</i> Ostenfeld	X	XX	XX
<i>C. socialis</i> Lauder	X	X	-
<i>C. subtilis</i> Cleve	X	X	-
<i>C. tetrastichon</i> Cleve	X	X	X
<i>C. tortissimus</i> Gran	X	XX	XX
<i>C. weissflogii</i> Schütt	X	X	-
<i>C. vanheurecki</i> Gran	X	X	X
<i>Climacodiam biconcavum</i> Cleve	XX	XX	XX
<i>C. frauenfeldianum</i> Grunow	XX	XX	XX
<i>Cocconeis</i> spp.	-	-	X
<i>Corethron hystris</i> Hensen	XX	XX	XX
<i>Coscinodiscus centralis</i> Ehrenberg	X	XX	XX
<i>C. concinniformis</i> Simonsen	X	-	-
<i>C. concinnus</i> W. Smith	X	XX	X
<i>C. gigas</i> Ehrenberg	X	X	XX
<i>C. granii</i> Gough	X	-	-
<i>C. jonesianus</i> ( Greville ) Ostenfeld	XX	XX	XX
<i>C. perforatus</i> Ehrenberg	X	X	X
<i>C. radiatus</i> Ehrenberg	X	X	X
<i>C. reniformis</i> Castracane	-	-	X
<i>C. thorii</i> Pavillard	X	X	X
<i>C. weilesii</i> Gran & Angst	X	X	X
<i>Cyclotella</i> spp.	X	XX	XX
<i>Cylindrotheca closterium</i> ( Ehrenberg ) Reimann & Lewin	XX	XX	XX
<i>Cymatosira lorenziana</i> Grunow	-	X	X
<i>Dactyliosolen blavyanus</i> ( Bergon ) Hasle	-	X	X
<i>D. fragilissimus</i> ( Bergon ) Hasle	-	X	-
<i>D. phuketensis</i> ( Sundström ) Hasle	X	X	X
<i>Diploneis</i> spp.	-	XX	XX
<i>Detonula pumila</i> ( Castracane ) Gran	X	XX	XX
<i>Ditylum brightwellii</i> ( West ) Grunow	XX	XX	XX
<i>D. sol</i> Grunow	XX	XX	XX
<i>Entomoneis</i> spp.	XX	XX	XX
<i>Eucampia cornuta</i> ( Cleve ) Grunow	X	X	XX
<i>E. zodiacus</i> Ehrenberg	X	X	X
<i>Fragilaria cylindrus</i> Grunow	X	XX	XX
<i>F. oceanica</i> Cleve	X	X	X



**Table 2.** (Continued).

Species	Sampling levels		
	S	Th	Ch
<i>F. striatula</i> Lyngbye	X	XX	XX
<i>Fragilariopsis doliolus</i> ( Wallich ) Medlin & Sims	X	XX	XX
<i>Gossleriella tropica</i> Schütt	X	XX	XX
<i>Guinardia cylindrus</i> ( Cleve ) Hasle	XX	XX	XX
<i>G. flaccida</i> ( Castracane ) H. peragallo	XXX	XX	XXX
<i>G. stiata</i> ( Stolterfoth ) Hasle	XX	XX	XX
<i>Gyrosigma</i> . spp.	X	X	X
<i>Halicotheca thamensis</i> ( Shrubsole ) Ricard	X	X	X
<i>Haslea gigantea</i> (Hustedt) Simonsen	XX	XX	XX
<i>H. wawriake</i> ( Hustedt ) Simonsen	X	XX	XX
<i>Hemiaulus hauckii</i> Grunow	XX	XX	XX
<i>Hemiaulus indicus</i> Karsten	X	X	X
<i>H. membranacea</i> Cleve	XX	XXX	XX
<i>H. sinensis</i> Greville	XX	XX	XX
<i>Hemidiscus cuneiformis</i> Wallich	X	X	X
<i>Lauderia annulata</i> Gran	X	XX	X
<i>Leptocylindrus danicus</i> Cleve	X	X	X
<i>L. mediterraneus</i> ( H. Peragallo ) Hasle	X	X	XX
<i>Lioloma delicatulum</i> ( Cupp ) Hasle	X	X	X
<i>L. elongatum</i> ( Grunow ) Hasle	-	X	X
<i>L. pacificum</i> ( Cupp ) Hasle	-	XX	XX
<i>Lithodesmium undulatum</i> Ehrenberg	X	X	-
<i>Melosira nummuloides</i> C.A.Agardh	X	X	X
<i>Meuniera membranacea</i> ( Cleve ) P.C.Silva	XX	XX	XX
<i>Navicula distans</i> ( W.Smith ) Ralfs	X	X	X
<i>N. transitrans</i> (Grunow ) Cleve	-	X	X
<i>N.</i> spp.	X	X	X
<i>Neostreptothea subindica</i> von Stosch	X	X	X
<i>Nitzschia bicapitata</i> Cleve	X	X	X
<i>N. longissima</i> ( Bre'bisson ) Ralfs	X	X	X
<i>N. frigida</i> Grunow	XX	XX	XX
<i>N.</i> spp.	X	X	X
<i>Odontella mobiliensis</i> ( Bailey ) Grunow	X	XX	XX
<i>O. sinensis</i> ( Greville ) Grunow	XX	XX	XX
<i>Pachynesis gerlachii</i> Simonsen	X	XX	XX
<i>Palmeria hardmaniana</i> Greville	-	XX	XX
<i>P. ostenfeldii</i> ( Ostenfeld ) von Stosch	-	X	-
<i>Paralia sulcata</i> ( Ehrenberg ) Cleve	XX	XX	XX
<i>Planktoniella blanda</i> ( A. Schmidt ) Syvertsen & Hasle	-	X	X
<i>P. sol</i> ( Wallich ) Schütt	X	XX	XX
<i>Pleurosigma angulatum</i> W. Smith	X	X	-
<i>P. normanii</i> Ralf	XX	XX	XXX
<i>P.</i> spp.	XX	XX	XX
<i>Porosira denticulata</i> Simonsen	-	X	X
<i>Proboscia alata</i> ( Brightwell ) Sundström	XXX	XXX	XXX
<i>Pseudoguinardia recta</i> von Stosch	X	X	X
<i>Pseudo-nitzschia australis</i> Frenguelli	X	X	X
<i>P. cuspidata</i> (Hasle) Hasle	-	X	-
<i>P. pseudodelicatissima</i> ( Hasle ) Hasle	XX	XX	XX
<i>P. pungens</i> ( Grunow & Cleve ) Hasle	XX	XX	XX
<i>P. subpacifica</i> ( Hasle ) Hasle	-	X	X
<i>P.</i> spp.	-	X	X
<i>Pseudosolenia calcar - avis</i> ( Chultz ) Sundström	XXX	XXX	XXX

Table 2. (Continued).

Specices	Sampling levels		
	S	Th	Ch
<i>Rhizosolenia acuminata</i> ( H. Peragallo ) Gran	X	X	X
<i>R. bergonii</i> H. Peragallo	X	X	XX
<i>R. castracanei</i> var. <i>castracanei</i> H. Peragallo	X	X	X
<i>R. castracanei</i> var. <i>neglecta</i> Sundström	-	XX	X
<i>R. clevei</i> var. <i>clevei</i> Ostenfeld	XX	XX	X
<i>R. clevei</i> var. <i>communis</i> Sundström	X	X	XX
<i>R. formosa</i> H. Peragallo	X	X	X
<i>R. hyalina</i> Ostenfeld	X	XX	XX
<i>R. imbricata</i> Brightwell	X	X	X
<i>R. robusta</i> Norman	X	X	X
<i>R. setigera</i> Brightwell	X	XX	XX
<i>R. styliformis</i> Brighthwell	XX	XX	XX
<i>Stephanopyxis palmeriana</i> ( Greville ) Grunow	X	X	XX
<i>Thalassionema bacillare</i> ( Heiden ) Kolbe	-	X	X
<i>T. frauenfeldii</i> ( Grunow ) Hallegraeff	XXX	XXX	XXX
<i>Thalassionema. nitzschoides</i> ( Grunow ) Mereschkowsky	XXX	XX	XXX
<i>T. pseudonitzschoides</i> ( Schuette & Schrader ) Hasle	-	X	X
<i>Thalassiothrix longissima</i> Cleve & Grunow	X	XX	XX
<i>T. gibbura</i> Hasle	-	X	X
<i>Thalassiosira eccentrica</i> ( Ehrenberg ) Cleve	XX	XX	XX
<i>T. leptopus</i> ( Grunow ) Hasle & G. Fryxell	X	X	-
<i>T. lineata</i> Jouse'	X	X	-
<i>T. oestrupii</i> ( Ostenfeld ) Hasle	-	X	-
<i>T. subtilis</i> ( Ostenfeld ) Gran	XX	XX	-
<i>T. thailandica</i> Boonyapiwat	X	-	-
<i>T. spp.</i>	XX	XX	XX
<i>Triceratium favas</i> Ehrenberg	-	X	-
<i>Tropidoneis</i> sp.	-	X	X
Phylum Dinophyceae ( Dinoflagellate )			
<i>Alexandrium affine</i> ( Inoue & Fukuyo ) Balech	X	-	-
<i>A. compressum</i> ( Fukuyo, Yoshida & inoue ) Balech	-	X	-
<i>A. concavum</i> ( Gaarder ) Balech	-	-	X
<i>A. fraterculus</i> ( Balech ) Balech	X	X	-
<i>A. leei</i> Balech	X	X	-
<i>A. tamarensense</i> ( Lebour ) Balech	X	X	-
<i>A. tamiyavanichi</i> Balech	XX	XX	XX
<i>A. spp.</i>	X	X	X
<i>Amphidinium</i> spp.	X	X	-
<i>Amphisolenia bidentata</i> Schroder	XX	XX	XX
<i>A. schauinslandii</i> Lemmermann	X	X	-
<i>A. trinax</i> Schütt	-	X	X
<i>Amylex triacantha</i> ( Jörgensen ) Sournia	-	X	X
<i>Centrodinium</i> sp.	-	X	X
<i>Ceratium azoricum</i> Cleve	X	X	-
<i>C. belone</i> Cleve	X	-	-
<i>C. biceps</i> Claparede & Lachmann	-	X	X
<i>C. bigelowii</i> Kofoed	-	X	X
<i>C. boehmii</i> Graham & Bronikosky	XX	XX	XX
<i>C. candelabrum</i> ( Ehrenberg ) Stein	XX	X	X
<i>C. carriense</i> Gourret	XX	XX	XX
<i>C. concillians</i> Jörgensen	X	X	X



**Table 2.** (Continued).

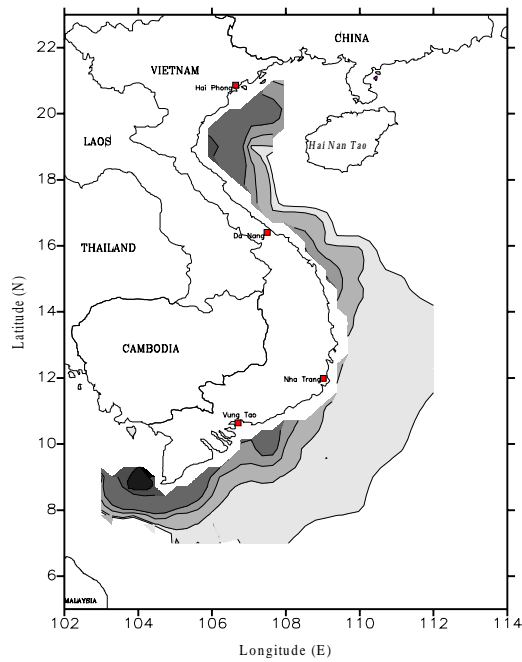
Specices	Sampling levels		
	S	Th	Ch
<i>C. contortum</i> var. <i>contortum</i> (Gourret) Cleve	X	X	-
<i>C. contortum</i> var. <i>sultans</i> (Shroder) Jörgensen	X	X	X
<i>C. declinatum</i> var. <i>declinatum</i> (Karsten) Jorgensen	X	X	X
<i>C. declinatum</i> var. <i>angusticorneum</i> (Karsten) Jorgensen	XX	XX	XX
<i>C. deflexum</i> (Kofoid) Jörgensen	X	XX	-
<i>C. dens</i> Ostenfeld & Schmidt	XX	XX	XX
<i>C. falcatum</i> (Kofoid) Jörgensen	X	X	X
<i>C. furca</i> (Ehrenberg) Claparede & Lachmann	XX	XX	XX
<i>C. fusus</i> (Ehrenberg) Dujardin	XX	XX	XX
<i>C. gibberum</i> Gourret	X	X	X
<i>C. gravidum</i> Gourret	-	X	X
<i>C. hexacanthum</i> Gourret	-	X	X
<i>C. horridum</i> (Cleve) Gran	XX	XX	XX
<i>C. humile</i> Jörgensen	XX	XX	XX
<i>C. incisum</i> (Karsten) Jörgensen	X	-	-
<i>C. inflatum</i> (Kofoid) Jörgensen	X	X	X
<i>C. kofoidii</i> Jörgensen	XX	XX	XX
<i>C. longipes</i> (Bailey) Gran	X	-	-
<i>C. limulus</i> Gourret	X	-	-
<i>C. lunula</i> (Schimpe) Jörgensen	X	X	X
<i>C. macroceros</i> (Ehrenberg) Vanholf	XX	X	X
<i>Ceratium massiliense</i> (Gourret) Karsten	X	X	-
<i>C. pentagonum</i> Gourret	X	X	X
<i>C. platycorne</i> Daday	-	-	X
<i>C. praelongum</i> (Lemmermann) Kofoid	-	X	X
<i>C. ranipes</i> Cleve	X	X	XX
<i>C. reflexum</i> (Cleve)	X	-	-
<i>C. schroeteri</i> Schroder	-	X	X
<i>C. symmetricum</i> Pavillard	X	-	-
<i>C. teres</i> Kofoid	XX	XX	XX
<i>C. trichoceros</i> (Ehrenberg) Kofoid	XX	XX	XX
<i>C. tripos</i> (O.F. Muller) Nitzsch	XX	X	X
<i>C. vulture</i> Cleve	X	XX	XX
<i>Ceratocorys armata</i> (Schütt) Kofoid	-	X	-
<i>C. gorretii</i> Paulsen	-	X	X
<i>C. horrida</i> Stein	XX	XX	XX
<i>Citharisthes regius</i> Stein	-	X	X
<i>C. apsteinii</i> Schütt	-	X	-
<i>Corythodinium globosum</i> Jorgensen	-	X	-
<i>C. tessellatum</i> (Stein) Loeblich Jr. & Loeblich	X	XX	XX
<i>Dinophysis acuminata</i> Claparede & Lachmann	-	X	X
<i>D. caudata</i> Saville - Kent	XX	XX	XX
<i>D. hastata</i> Stein	X	X	-
<i>D. infundibula</i> Schiller	X	X	X
<i>D. miles</i> Cleve	X	X	XX
<i>D. recurva</i> Kofoid & Skorgsberg	X	-	-
<i>D. schuettii</i> Murray & Whitting	X	X	X
<i>D. uracantha</i> Stein	X	XX	XX
<i>Diplopsalis lenticulata</i> Berg	X	X	XX
<i>D. spp.</i>	-	X	X
<i>Diplopsalopsis</i> sp.	-	X	X
<i>Fragilidium</i> spp.	X	XX	XX
<i>Goniodoma polyedricum</i> (Pouchet) Jörgensen	XX	XX	XX

Table 2. (Continued).

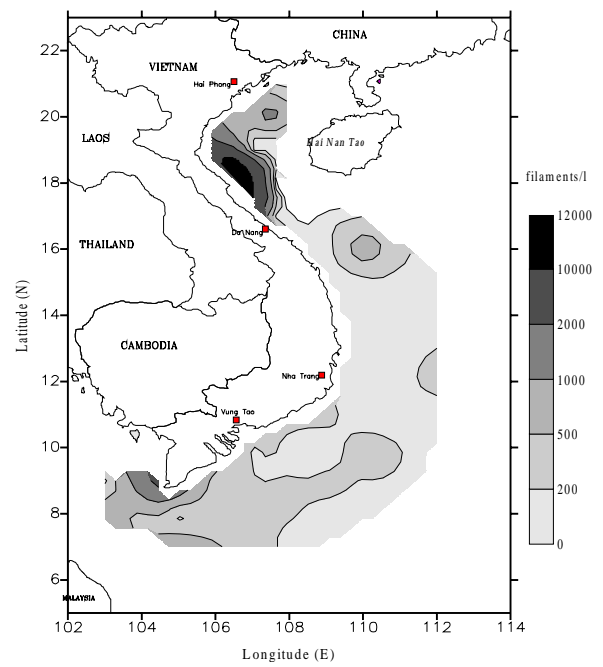
Specices	Sampling levels		
	S	Th	Ch
<i>Gonyaulax digitale</i> ( Pouchet ) Jörgensen	X	X	X
<i>G. fragilis</i> ( Schütt ) Kofoid	-	X	X
<i>G. glyphorhynchus</i> Murry & Whitting	-	X	X
<i>G. hyalina</i> Ostenfeld & Whitting	-	XX	X
<i>G. milneri</i> ( Murray & Whitting ) Kofoid	-	-	X
<i>G. pacifica</i> Kofoid	-	XX	X
<i>G. polygramma</i> Stein	XX	XX	XX
<i>G. scrippsae</i> Kofoid	-	XX	X
<i>G. spinifera</i> ( Claparede & Lachmann ) Diesing	XX	XX	XX
<i>G. verior</i> Sournia	-	X	X
<i>G. spp.</i>	XX	XX	XX
<i>Gymnodinium sanguineum</i> Hirasaka	X	X	X
<i>G. spp.</i>	XX	XX	XX
<i>Gyrodinium spp.</i>	-	X	X
<i>Heterocapsa spp.</i>	X	X	X
<i>Heterodinium blackmanii</i> ( Murray & Whitting ) Kofoid	X	X	-
<i>H. globosum</i> Kofoid	-	-	X
<i>Heterodinium rigdenae</i> Kofoid	-	X	X
<i>Histioneis depressa</i> Schiller	-	-	X
<i>H. pulchra</i> Kofoid	-	X	X
<i>H. spp.</i>	X	X	X
<i>Kofoidnium sp.</i>	X	X	X
<i>Lingulodinium polyedrum</i> ( Stein ) Dodge	X	X	X
<i>Ornithocercus formosus</i> Kofoid	-	X	-
<i>O. heteroporus</i> Kofoid	-	X	X
<i>O. magnificus</i> Stein	-	X	X
<i>Ornithocercus quadratus</i> Schutt	X	X	X
<i>O. splendidus</i> Schütt	-	X	X
<i>O. steinii</i> Schutt	-	X	-
<i>O. thumii</i> ( A. Schmidt ) Kofoid & Skogsberg	XX	XX	XX
<i>Oxytoxum parvum</i> Schiller	-	X	X
<i>O. scolopax</i> Stein	XX	XX	XX
<i>O. subulatum</i> Kofoid	X	XX	XX
<i>Phalacroma acutoides</i> Balech	X	X	X
<i>P. argus</i> Stein	X	X	X
<i>P. circumsutum</i> Karsten	X	X	X
<i>P. doryphorum</i> Stein	XX	XX	XX
<i>P. favus</i> Kofoid & Michener	X	X	-
<i>P. parvulum</i> ( Schütt ) Jörgensen	X	-	X
<i>P. rapa</i> Stein	X	-	-
<i>P. rotundatum</i> ( Claparede & Lachmann ) Kofoid & Michener	XX	XX	XX
<i>P. rudgei</i> Murry & Whitting	-	X	X
<i>Podolampas bipes</i> Stein	XX	XX	XX
<i>P. palmipes</i> Stein	XX	XX	XX
<i>P. spinifera</i> Okamura	XX	XX	XX
<i>Preperidinium meunieri</i> ( Pavillard ) Elbacher	X	XX	-
<i>Prorocentrum balticum</i> ( Lohmann ) Loeblich	-	X	X
<i>P. compressum</i> ( Bailey ) Abe' & Dodage	XX	XX	XX
<i>P. concavum</i> Fukuyo	-	-	X
<i>P. emarginatum</i> Fukuyo	-	-	XX
<i>P. mexicanum</i> Tafall	-	-	X
<i>P. micans</i> Ehrenberg	X	X	X
<i>P. sigmoides</i> Böhm	X	X	X

**Table 2.** (Continued).

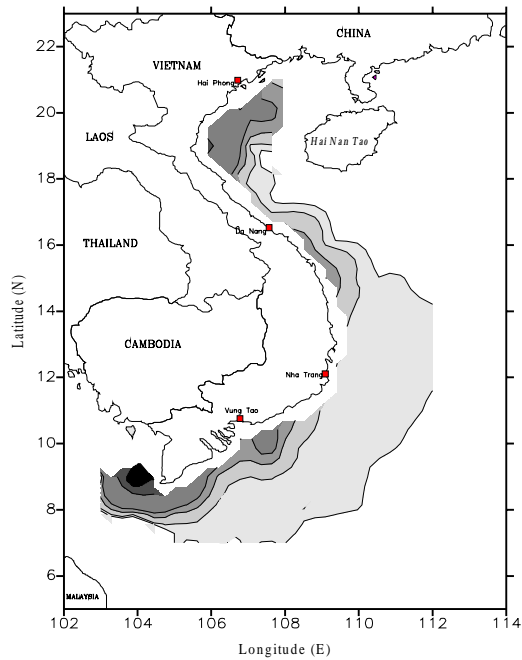
Species	Sampling levels		
	S	Th	Ch
<i>Protoceratium spinulosum</i> (Murray & Whitting) Schiller	X	X	X
<i>Protopteridinium abei</i> (Abe') Balech	X	XX	X
<i>P. angustum</i> P. Dangeard	-	-	X
<i>P. cerasus</i> Paulsen	-	X	-
<i>P. claudicans</i> (Paulsen) Balech	-	-	X
<i>P. conicum</i> (Gran) Balech	XX	XX	XX
<i>P. crassipes</i> (Kofoid) Balech	XX	X	-
<i>P. curtipes</i> (Jørgensen) Balech	-	X	-
<i>P. depressum</i> (Baley) Balech	XX	XX	XX
<i>P. diabolus</i> (Cleve) Balech	X	X	X
<i>P. divaricatum</i> (Meunier) Balech	-	X	-
<i>P. divergens</i> (Ehrenberg) Balech	XX	XX	XX
<i>P. elegans</i> (Cleve) Balech	XX	XX	XX
<i>P. grande</i> (Kofoid) Balech	XX	XX	XX
<i>P. hirobis</i> (Abe') Balech	XX	X	-
<i>P. latispinum</i> (Mangin) Balech	X	X	X
<i>P. leonis</i> (Pavillard) Balech	XX	X	-
<i>P. murrayi</i> (Kofoid) Balech	X	X	-
<i>P. minutum</i> Kofoid	X	-	-
<i>P. nipponicum</i> (Abe') Balech	X	-	-
<i>P. oceanicum</i> (Vanholf) Balech	XX	XX	XX
<i>P. okamurai</i> (Abe') Balech	X	X	-
<i>P. ovum</i> (Schiller) Balech	X	X	-
<i>P. pacificum</i> Kofoid & Michener	XX	XX	XX
<i>P. pallidum</i> (Ostenfeld) Balech	X	XX	X
<i>P. pellucidum</i> Bergh	X	X	X
<i>P. pentagonum</i> (Gran) Balech	X	X	-
<i>P. quanerense</i> (Schroder) Balech	X	X	X
<i>P. roseum</i> Balech	-	X	-
<i>P. spinulosum</i> (Schiller) Balech	X	X	X
<i>P. stenii</i> (Jørgensen) Balech	XX	XX	XX
<i>Protopteridinium subinerme</i> (Paulsen) Balech	XX	XX	X
<i>P. subpuriforme</i> P. Dangeard	-	X	-
<i>P. tenuisimum</i> Kofoid	-	-	X
<i>P. thorianuum</i> (Paulsen) Balech	-	X	-
<i>P. trisylum</i> Stein	X	-	-
<i>P. tumidum</i> Okamura	-	X	-
<i>P. spp.</i>	XX	XX	XX
<i>Pyrocystis fusiformis</i> Wyville - Thomson ex Blachman	XX	XX	XX
<i>P. hamulus</i> Cleve	XX	XX	X
<i>P. lunula</i> species complex	XX	XX	XX
<i>P. noctiluca</i> Murray ex Haeckel	XX	XX	XX
<i>Pyrophacus horologium</i> Stein	X	X	X
<i>P. steinii</i> (Schiller) Wall & Dale	X	X	X
<i>Scripsiella trochoidea</i> (Stein) Balech	XX	XX	X
<i>S. spp.</i>	XX	XX	XX
<i>Schuetiella mitra</i> (Schütt) Balech	-	X	X
<i>Sinophysis</i> spp.	X	-	-
<i>Spiraulax kofoidii</i> Graham	-	X	X
<i>Triposolenia truncata</i> Kofoid	X	X	X



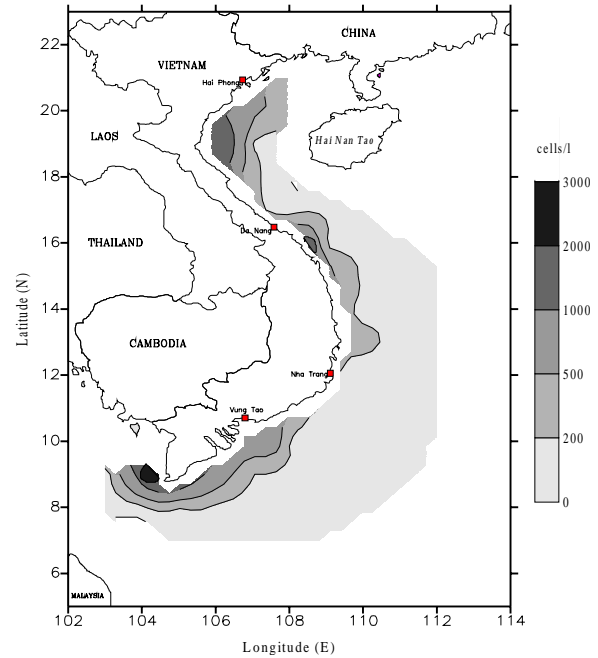
**Fig. 2.** Phytoplankton abundance at surface.



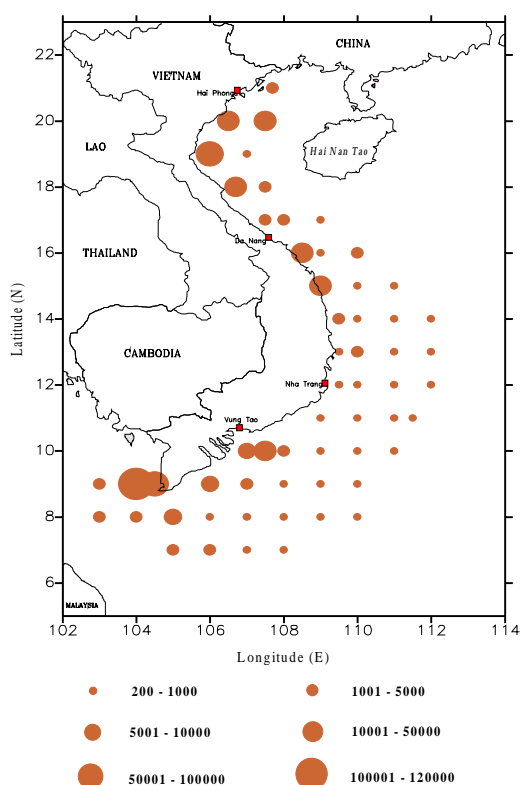
**Fig. 3.** Abundance of blue green algae at surface.



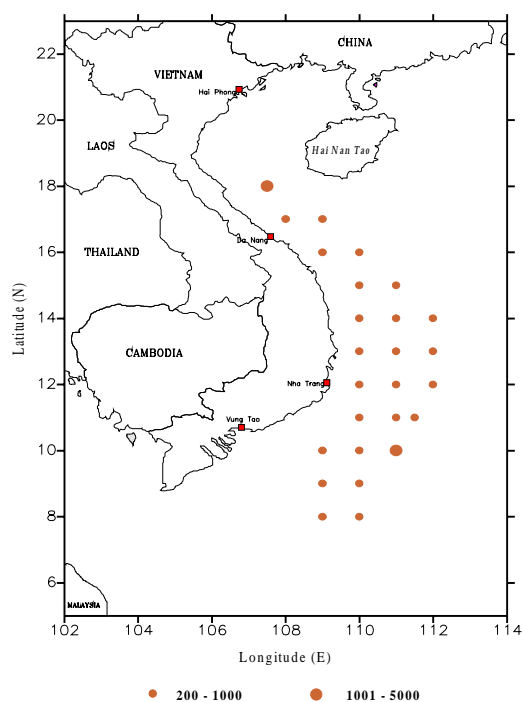
**Fig. 4.** Abundance of diatom at surface.



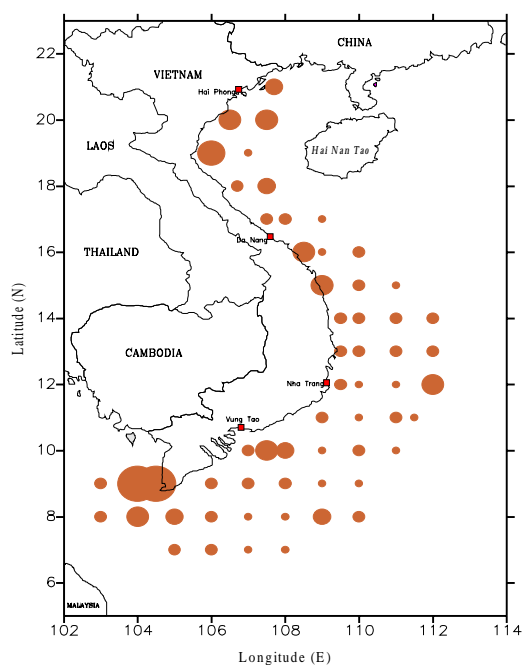
**Fig. 5.** Abundance of dinoflagellate at surface.



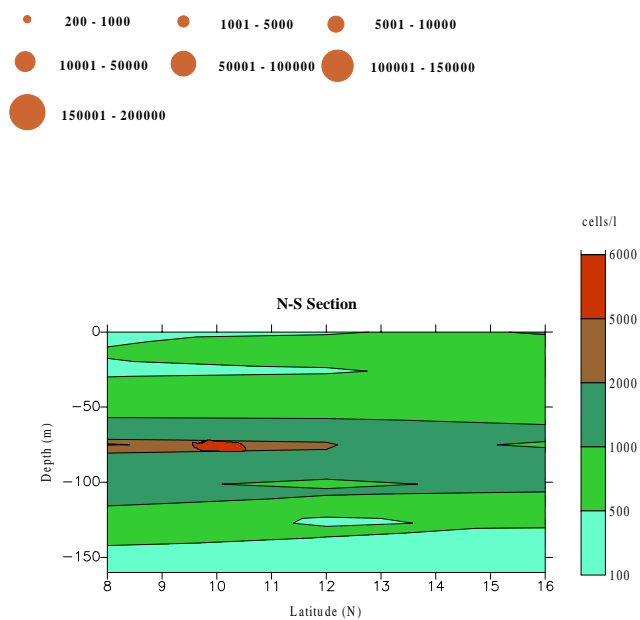
**Fig. 6.** Phytoplankton densities (cells/l) at surface.



**Fig. 7.** Phytoplankton densities (cells/l) at thermocline depth.



**Fig. 8.** Phytoplankton densities (cells/l) at chlorophyll maximum depth.



**Fig. 9.** Vertical cross section of phytoplankton density.

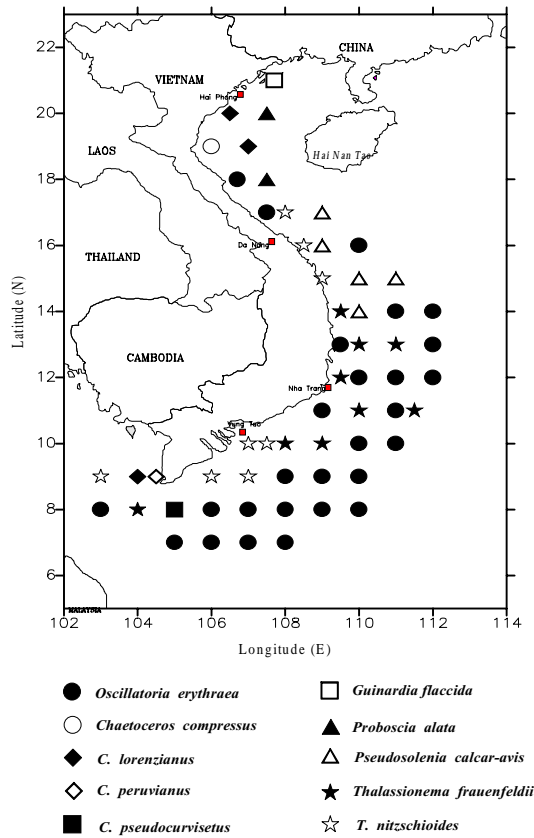


Fig. 10. Dominant species at surface.

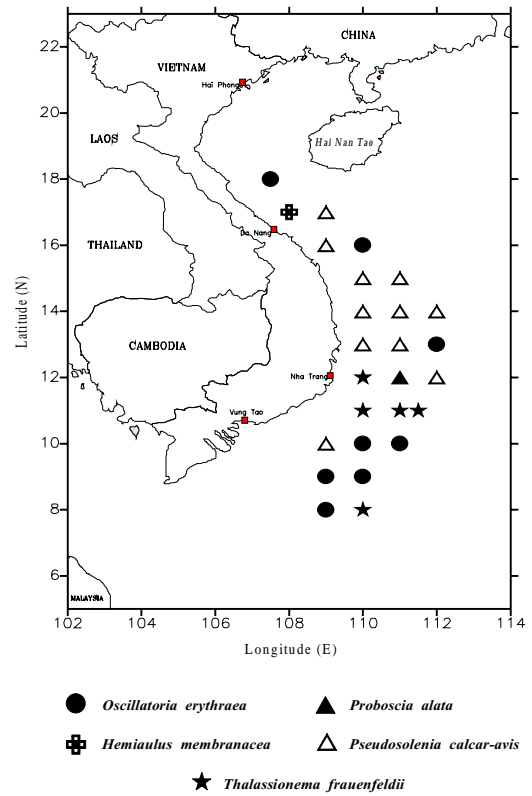


Fig. 11. Dominant species at thermocline depth.

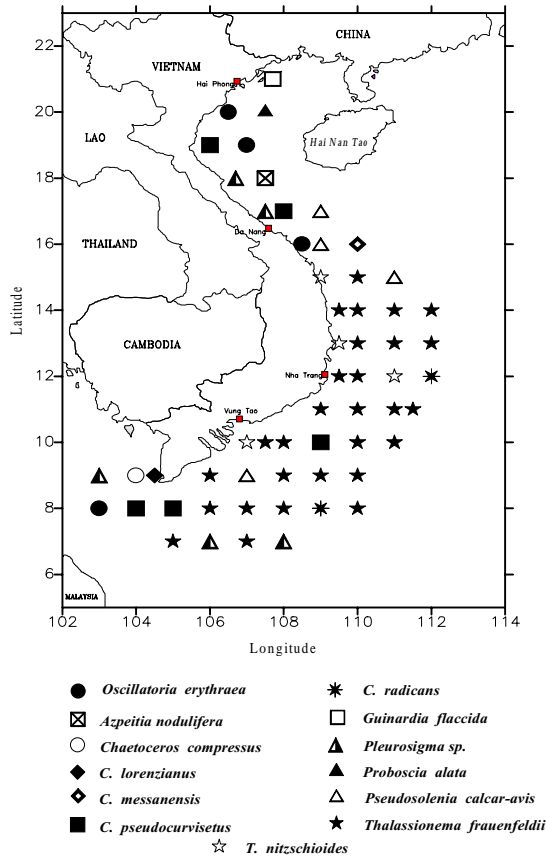


Fig. 12. Dominant species at chlorophyll maximum depth.

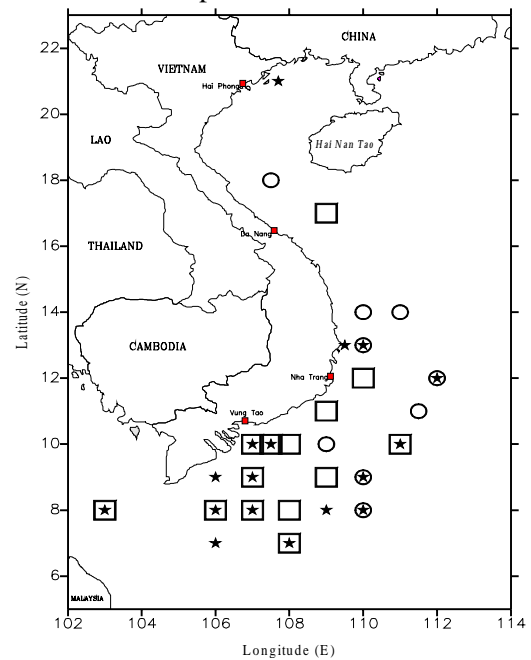


Fig. 13. Distribution of *Alexandrium* spp. at different depths.



**Table 3.** Phytoplankton species numbers, richness indices (R), diversity indices ( $H'$ ) and evenness indices (E) in 3 parts of study area.

Part	SD	Species number				R		H'		E	
		Diatom		Dinoflagellate							
		Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
North (Gulf of Tonkin)	S	21-49	35	10-23	17	1.26-3.41	2.47	0.89-3.92	3.05	0.22-0.91	0.75
	Th	20-38	27	14-23	19	1.86-2.82	2.49	2.99-3.42	3.15	0.79-0.83	0.82
	Ch	20-54	37	6-29	17	1.35-2.94	2.27	2.15-3.47	2.98	0.58-0.84	0.76
Central	S	9-45	19	9-33	19	1.45-3.32	2.48	1.55-3.37	2.70	0.43-0.87	0.74
	Th	10-33	18	10-33	20	1.93-3.12	2.67	1.78-3.16	2.77	0.52-0.87	0.78
	Ch	14-53	35	5-26	14	1.37-3.13	2.14	2.12-3.32	2.80	0.60-0.87	0.78
South	S	8-44	22	8-25	13	1.09-3.09	1.97	1.66-3.17	2.44	0.48-0.83	0.68
	Th	7-21	14	11-20	14	1.21-3.12	1.94	0.73-3.05	1.86	0.22-0.82	0.55
	Ch	15-50	30	2-26	11	1.01-2.42	1.68	1.67-3.34	2.58	0.41-0.84	0.70

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